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THE DISTANCE TRAVELLED FROM REST TO TERMINAL VELOCITY BY A SPHERE IN AIR. (U)

by

10 Stanley B. Mellsen

Project No. 20-90-03

WUD 13E01

11 September 1978

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ABSTRACT

The distance travelled as a function of velocity for falling spherical drops starting from rest was calculated. This was done for 1 to 5 millimetre spheres to determine the travel distance required for designing experiments where velocities approaching terminal are required. The results showed that 80 percent of terminal velocity is reached after spheres of unit density and diameter of 5 millimetres have fallen from rest through a distance of 7.5 metres. To achieve 85 percent of terminal velocity, an increase of only 5 percent, 9.5 metres is required. Also calculated was the velocity of particles blown upward from rest in a vertical airstream. This was done to provide information for comparison of experimental to theoretical results on the effect of dust on aerodynamic drag.

(U)

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NOTATION

a and b	simplifying constants
C_D	drag coefficient of a sphere in air
D	drag force due to air resistance
d	spherical drop diameter
g	acceleration due to gravity
m	mass of sphere
m_e	effective mass of sphere in air due to buoyancy effects
Re	Reynolds number of a sphere
t	time after sphere starts to move
u	free stream air velocity
v	velocity of sphere
v_*	upward terminal velocity of a sphere in a vertical air stream
v_s	slip velocity of a sphere in a vertical air stream
v_t	terminal velocity of a spherical particle
x	displacement of sphere from rest
γ	surface tension of the liquid
μ	dynamic viscosity of air
ν	kinematic viscosity of air
ρ_a	air density
ρ_ℓ	density of the liquid

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THE DISTANCE TRAVELLED FROM REST TO TERMINAL VELOCITY BY A SPHERE IN AIR (U)

by

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1. INTRODUCTION

The immediate purpose of this report is to provide information on the velocity as a function of distance fallen from rest for drops of various sizes of interest, and to describe the method by which this was achieved. The second purpose is to describe the determination of the upward velocity of spherical dust particles in a vertical stream of air. This information was necessary for comparing experimental to theoretical results in a study of impaction forces of dust on spheres and cylinders (Mellsen).

The mathematical theory and the solution of the equations of motion, for which computer programs are provided, are described herein.

2. THE PROBLEM

It has been shown experimentally that drops of various liquids falling through air deform to a negligible extent provided that the value of $\rho_\ell d^2 g/\gamma$ is below 0.4. For ordinary liquids this limiting value corresponds to drops which are 1 - 1.5 mm in diameter, and the terminal velocities reached, under any atmospheric conditions, by drops smaller than this can be calculated precisely from knowledge of the fluid resistance offered to the motion of spheres (Batchelor).

The work reported herein was undertaken to determine the distance travelled to terminal velocity by droplets 1 - 5 mm in diameter under any atmospheric conditions. Although this range of drop sizes falls outside the limiting value described above, the assumption of spherical drops was used. This provides sufficient accuracy for the purpose of designing experimental apparatus. The exact discrepancies were not obtained but they are certainly less than the discrepancies in the terminal velocities themselves, which were obtained by comparing the calculated terminal velocities of spheres to those of water drops determined by Best's empirical equation (Batchelor). The reason that the discrepancy in distance travelled to terminal velocity is less than the discrepancy in the terminal velocity is that the drag force gradually increases as the drop travels from rest to terminal velocity, and, correspondingly, the distortion of the drop increases to maximum deviation from spherical shape at terminal velocity.

3. THE MATHEMATICAL SOLUTION

a) Terminal Velocity of Spherical Drops

Equating the drag acting on a rigid sphere of diameter d and density ρ_ℓ, falling with steady velocity v_t to the effective weight of the sphere in air of density ρ_a, we have:

$$\frac{C_D \pi d^2 \rho_a v_t^2}{8} = \frac{\pi(\rho_\ell - \rho_a)d^3 g}{6} \qquad \text{(Eq. 1)}$$

where C_D, the drag coefficient, is a function of the Reynolds number $Re = vd/\nu$ which characterizes the motion of the sphere (Batchelor). Hence:

$$v_t^3 = \frac{4(\rho_\ell - \rho_a)g\nu Re^2}{3\rho_a C_D Re} \qquad \text{(Eq. 2)}$$

Eq. 2 was solved by an iterative technique. This was necessary because the drag coefficient is dependent upon the Reynolds number in a complex way so that the equation could not be solved explicitly for v_t. The dependency of drag coefficient on Reynolds number has been determined by a set of definitive equations for $C_D Re$ (Davies) based on the results of many experiments. These were solved for each Reynolds number as required by means of Newton's method. The initial estimate of $C_D Re$ chosen for use in Eq. 2 was the Stokes flow value of 24. This was substituted into Eq. 2 which was then solved for v_t. This value of v_t was then used to calculate $C_D Re$ which was in turn substituted into Eq. 2 and the process repeated. This iterative procedure was tested and found to converge rapidly.

The calculations for the terminal velocity were done by means of a subroutine in the computer program (Subroutine SBM 36, Appendix A). The values of $C_D Re$ needed in these calculations were obtained from a function subprogram (Function CDRE (RE), Appendix A).

b) Distance Travelled from Rest in Still Air as a Function of Velocity

The equation of motion of a spherical particle falling in air is given by:

$$m_e g - D = \frac{mdv}{dt} \qquad \text{(Eq. 3)}$$

where

$$m_e = \frac{\pi d^3(\rho_\ell - \rho_a)}{6} \qquad \text{(Eq. 4)}$$

$$m = \frac{\pi d^3 \rho_\ell}{6} \qquad \text{(Eq. 5)}$$

and

$$D = \frac{C_D \pi d^2 \rho_a v^2}{8} \qquad \text{(Eq. 6)}$$

To obtain the quantity $C_D Re$ for use in later calculations, the following form for the drag coefficient was used:

$$C_D = \frac{\mu C_D Re}{v d \rho_a} \qquad \text{(Eq. 7)}$$

Then, using Eq. 7, substitution of Eqs. 4, 5 and 6 into Eq. 3 gives the following equation for time from rest as a function of velocity:

$$t = \int_0^v \frac{dv}{a - bvC_D Re} \qquad \text{(Eq. 8)}$$

where

$$a = g\left(1 - \frac{\rho_a}{\rho_\ell}\right) \qquad \text{(Eq. 9)}$$

and

$$b = \frac{3\mu}{4\rho_\ell d^2} \qquad \text{(Eq. 10)}$$

Recognition that $dx = vdt$ gives the following equation for displacement as a function of velocity:

$$x = \int_0^v \frac{vdv}{a - bvC_D Re} \qquad \text{(Eq. 11)}$$

Eqs. 8 and 11 were solved by means of a computer program (Appendix A). The terminal velocity was first calculated by a subroutine (SBM 36, Appendix A) and the velocity increased by one percent increments up to ninety eight percent of terminal velocity, because terminal velocity is asymptotic. The quantity $C_D Re$ was found in each step by the function subprogram (CDRE (RE), Appendix A) and substituted in Eqs. 8 and 11 with the value of v to solve for t and x at each succeeding velocity.

c) Distance Travelled Upward From Rest in a Vertical Air Stream

The solution to this problem is similar to that of the problem described in the previous subsection with the following exceptions. The upward terminal velocity of the spherical particle is:

$$v_* = u - v_t \qquad \text{(Eq. 12)}$$

where v_t is terminal velocity calculated in air at rest as discussed earlier. The slip velocity of the particle, defined as the relative velocity between the air stream and sphere, is:

$$v_s = u - v \qquad \text{(Eq. 13)}$$

Eq. 6 becomes:

$$D = \frac{C_D \pi d^2 \rho_a v_s^2}{8} \qquad \text{(Eq. 14)}$$

Then Eqs. 8 and 11 become:

$$t = \int_0^v \frac{-dv}{a - bv_s C_D Re} \qquad \text{(Eq. 15)}$$

$$x = \int_0^v \frac{-vdv}{a - bv_s C_D Re} \qquad \text{(Eq. 16)}$$

The latter two equations were solved by a computer program (Appendix B) which was similar to the one previously described (Appendix A). The velocity was incremented by one percent of the upward terminal velocity instead of one percent of the terminal velocity in still air. The final increment was then at ninety percent of the upward terminal velocity, the asymptotic velocity in this particular case.

4. RESULTS

The elapsed times, velocities, distances, and fractions of terminal velocities were calculated for spheres of unit density falling from rest in still air. These are shown for diameters of 1 to 5 millimetres in 1/2 millimetre increments in the tables immediately following the listing of the computer program by means of which they were calculated (Appendix A). Also shown are the terminal velocities and, for comparison, the terminal velocities of water drops from Best's equation (Batchelor). The results are illustrated in the form of velocity versus distance curves for 1, 2, 3, 4 and 5 millimetre spheres (Fig. 1), and in terminal velocity versus diameter curves for rigid spheres compared to water drops (Fig. 2).

The elapsed times, velocities, distances travelled, and fractions of upward terminal velocities were calculated for spheres of specific gravity 2.6, corresponding to the density of glass beads used in experiments (Mellsen) on spheres starting from rest in a vertical air stream. An example of the results of these calculations is shown in the table following the listing of the computer program by means of which they were obtained (Appendix B). The results are illustrated in the form of curves of upward sphere velocity versus upward air velocity for three particle diameters (Fig. 3). These diameters and the distance travelled were used in previous experiments to measure drag on spheres and cylinders in dusty air. The results shown (Fig. 3) were used for comparison of theory to the results of these experiments and reported elsewhere (Mellsen). The program listed (Appendix B) was also used to provide direct numerical values for that work.

5. DISCUSSION

As can be seen (Fig. 1) better than 80 percent of terminal velocity was reached by the time spheres of unit density and maximum diameter of 5 millimetres had fallen from rest through a distance of 7.5 metres.

To achieve 85 percent of terminal velocity, an increase of only 5 percent, a distance of 9.5 metres was required. This indicated that, if a drop tube is to be used in experiments, a great deal of increase in length is required to gain little increase in velocity when approaching terminal velocity. However, a useful consequence of this asymptotic behavior is that the percentage of terminal velocity acquired by liquid drops is closely approximated by calculated percentages for spherical particles. The difference between terminal velocity for spheres of unit specific gravity and water drops increases with drop size (Fig. 2). However, the difference in percentage of terminal velocity reached for drop sizes of 1 to 5 millimetres is still negligible from the point of view of impaction test accuracy.

The curves of sphere velocity versus upward air velocity for a travel distance of 95 centimetres (Fig. 3) showed that terminal velocities were not reached for air velocities above 480 and 550 centimetres per second for particle diameters of 0.0470 and 0.0155 centimetres, respectively. Consequently, terminal velocities were not reached in experiments to which other calculations were compared (Mellsen). The applications and consequences of these results are described in the same reference.

6. CONCLUSIONS

Results of velocity versus distance for drops falling in still air and spherical dust particles blown upward in an air stream were obtained. These results are useful in the design or analysis of experiments where optimum travel distances are required or where travel distances are confined to available working space.

REFERENCES

Batchelor, G.K.	1956	"Surveys in Mechanics. The G.I. Taylor 10th Anniversary Volume". Cambridge University Press.
Davies, C.N.	1945	"Definitive Equations for the Fluid Resistance of Spheres". The Proc. of the Physical Society. Vol. 57, Part 4. July 1945.
Mellsen, S.B.	1978	"The Impaction Force of Airborne Particles on Spheres and Cylinders". Suffield Technical Paper No. 486. UNCLASSIFIED.

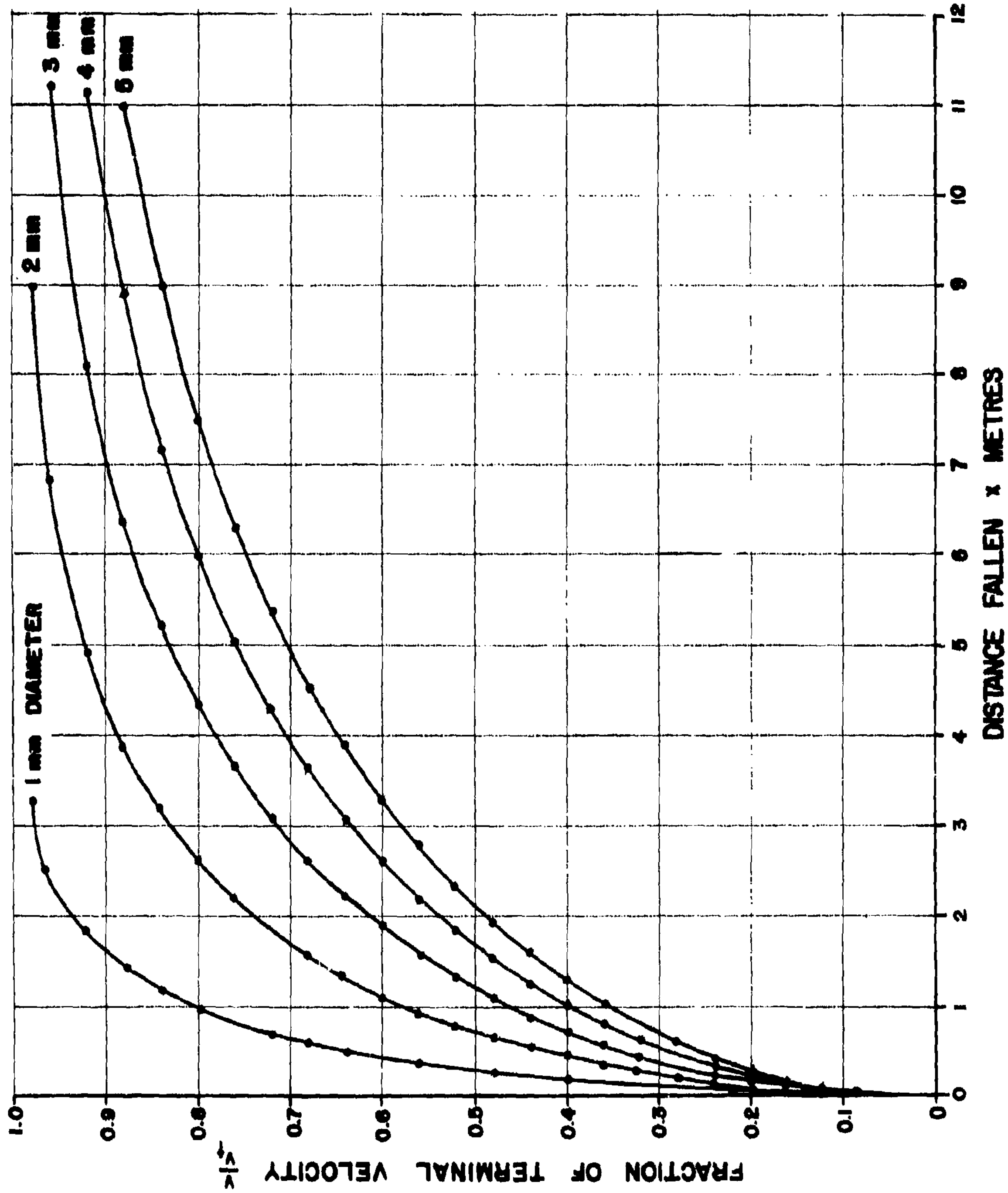

Figure 1: Velocity vs Distance for Spheres of Unit Density Falling from Rest in Still Air at 15°C and 76 cm Hg Pressure

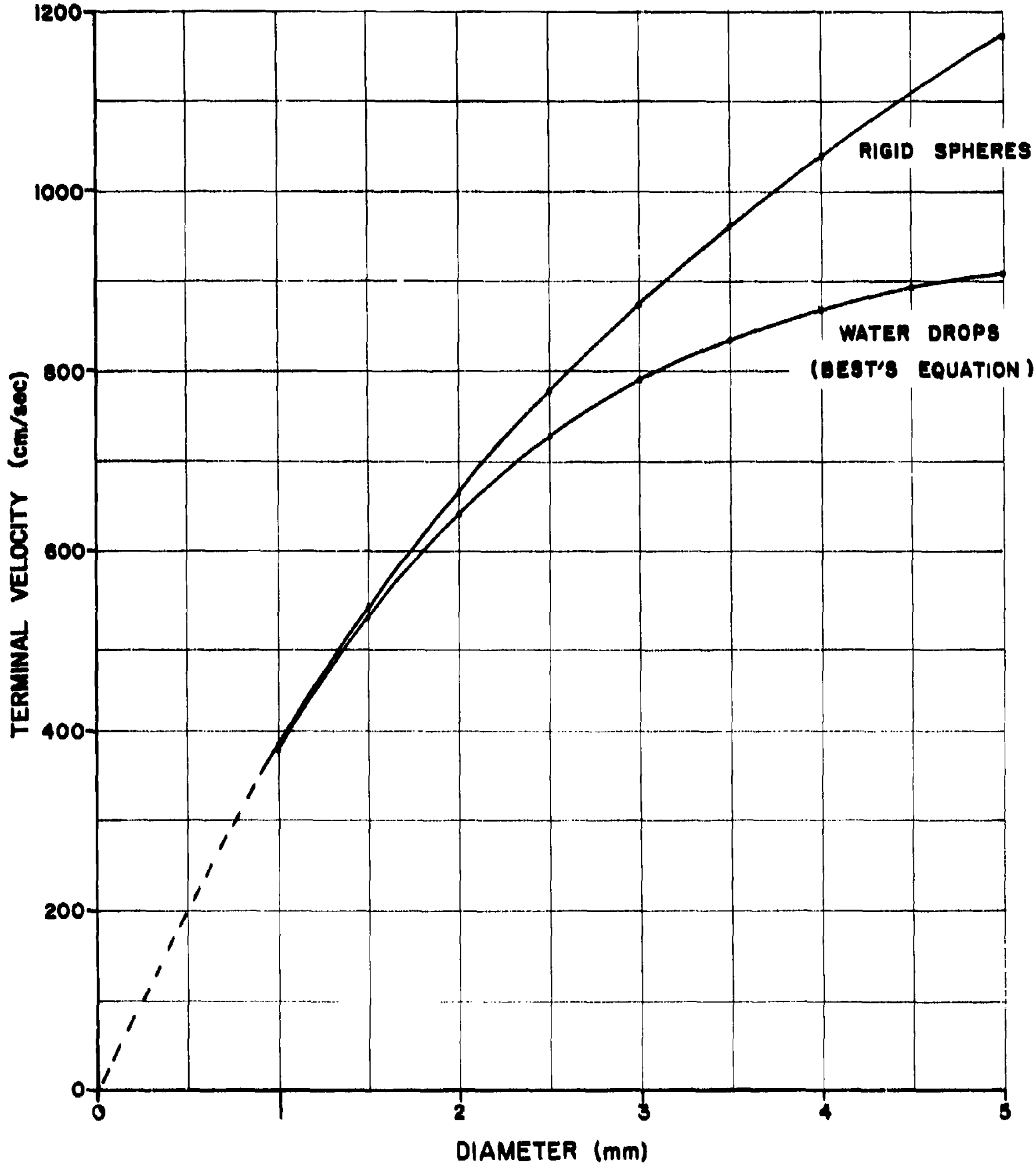

Figure 2: Terminal Velocities of Spheres of Unit Density Falling in Air at 15°C and 76 cm Hg Pressure

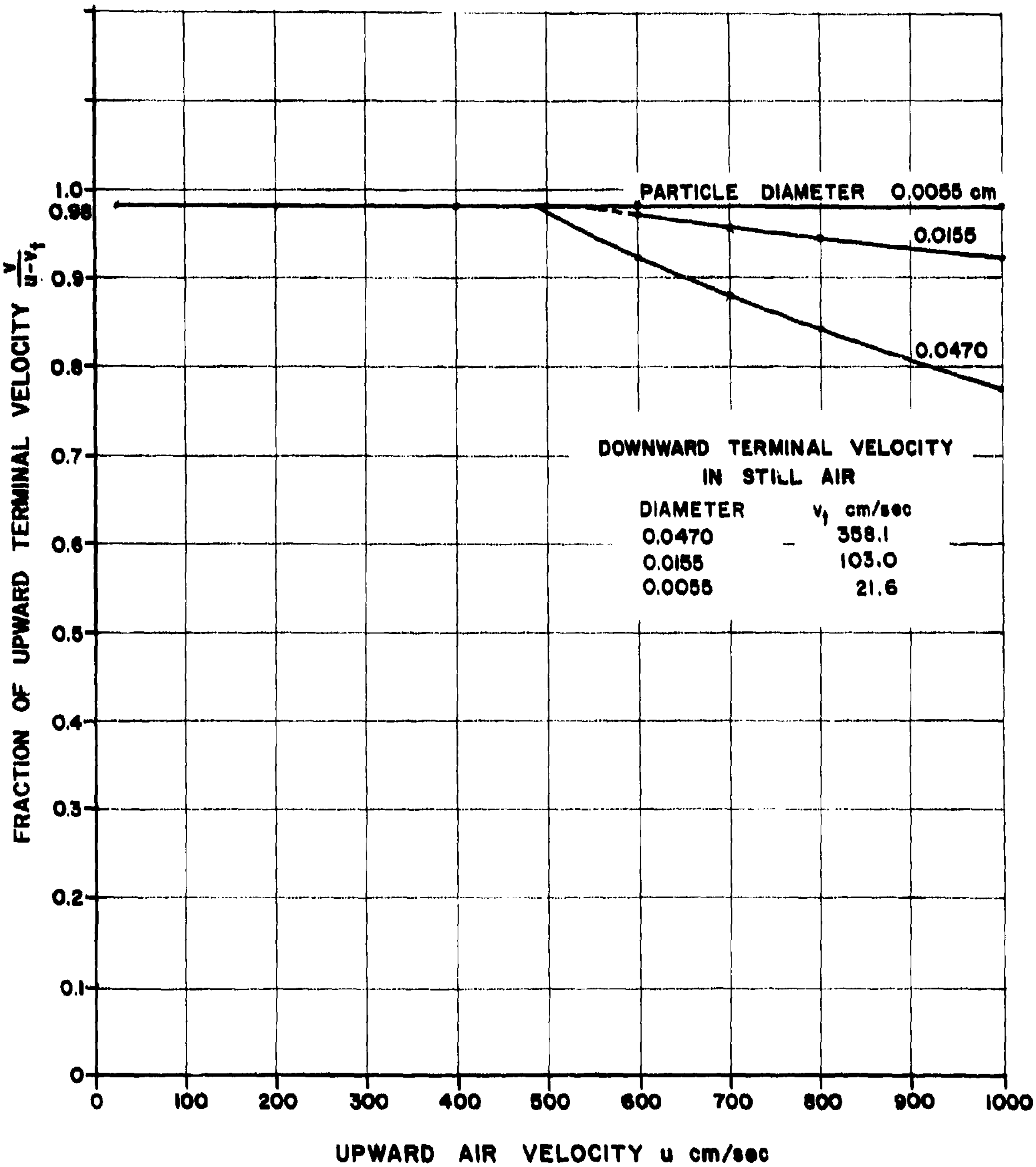

Figure 3: Upward Velocity of Spheres of Density 2.6 g cm^{-3} Starting From Rest 95 cm Upstream in a Vertical Air Stream at 15°C and 76 cm Hg Pressure

APPENDIX A

COMPUTER PROGRAM FOR DISTANCE TRAVELLED FROM REST TO TERMINAL VELOCITY FOR SPHERES IN STILL AIR

```
// JOB T

LOG DRIVE   CART SPEC   CART AVAIL  PHY DRIVE
  0000        0105        0105        0000

V2 M10   ACTUAL 16K  CONFIG 16K

// FOR
*ONE WORD INTEGERS
*LIST ALL
C
      FUNCTION CDRE(RE)
C
C     THIS FUNCTION COMPUTES THE PRODUCT OF DRAG COEFFICIENT
C     AND REYNOLDS NUMBER FOR A SPHERE AS A FUNCTION OF
C     REYNOLDS NUMBER LESS THAN 10000
C
C     CONSTANT COEFFICIENTS
C
      A1=1./24.
      A2=-2.3363*1.E-04
      A3=2.0154*1.E-06
      A4=-6.9105*1.E-09
      B0=-1.29536
      B1=9.86*1.E-01
      B2=-4.6677*1.E-02
      B3=1.1235*1.E-03
C
C     CHOOSE THE APPROPRIATE POLYNOMIAL
C
      IF(RE-4.0)2,7,7
C
C     INITIAL ESTIMATE
C
    2 IF(RE-0.00001)3,4,4
    3 CDRE = 24.0
      GO TO 50
    4 X=24.*RE
C
C     BEGIN NEWTON METHOD ITERATION
C
      CONTINUE
      DO 6 ITER=1,20
      FX=A1*X+A2*X**2+A3*X**3+A4*X**4-RE
      FPX=A1+2.*A2*X+3.*A3*X**2+4.*A4*X**3
      DELX=FX/FPX
```

```
      X=X-DELX
C
C     CHECK FOR CONVERGENCE
C
      EPS=1.E-06
      IF(ABS(DELX/X)-EPS)5,5,6
    5 CDRE=X/RE
      GO TO 50
    6 CONTINUE
      GO TO 29
C
C     INITIAL ESTIMATE
C
    7 CD = 1.0
      ELOG = 0.4342944819032 52
      X=ALOG(CD*RE**2)*ELOG
C
C     BEGIN NEWTON METHOD ITERATION
C
      DO 24 ITER=1,20
      FX=B0+B1*X+B2*X**2+B3*X**3 - ALOG(RE)*ELOG
      FPX=B1+2.*B2*X+3.*B3*X**2
      DELX=FX/FPX
      X=X-DELX
C
C     CHECK FOR CONVERGENCE
C
      EPS=1.E-06
      IF(ABS(DELX/X)-EPS)22,22,24
   22 CDRF=10.**X/RE
      GO TO 50
   24 CONTINUE
   29 WRITE(3,202)
   50 RETURN
C
C     FORMATS FOR OUTPUT STATEMENTS
C
  202 FORMAT(16H0 NO CONVERGENCE)
C
      END
VARIABLE ALLOCATIONS
   CDRE(R )=0000      A1(R )=0002      A2(R )=0004      A3(R )=0006      A4(R )=0008      B0(R )=000A
     B1(R )=000C      B2(R )=000E      B3(R )=0010       X(R )=0012      FX(R )=0014     FPX(R )=0016
   DELX(R )=0018     EPS(R )=001A      CD(R )=001C    ELOG(R )=001E    ITER(I )=0028

STATEMENT ALLOCATIONS
 202  =0059  2  =00A8  3  =00AF  4  =00B5  5  =012D  6  =0135  7  =0140  22  =01B8  24  =01C3  29  =01CC
```

```
PAGE   3

 50   =0100

FEATURES SUPPORTED
 ONE WORD INTEGERS

CALLED SUBPROGRAMS
 FABS     FALOG    FAXB     FADD     FSUB     FMPY     FDIV     FLD      FSTO     FSBR     FAXI     SWRT     SCOMP    SNR      SUBIN

REAL CONSTANTS
  .100000E 01=002A    .240000E 02=002C    .233630E 01=002E    .100000E-03=0030    .201540E 01=0032    .100000E-05=0034
  .691050E 01=0036    .100000E-08=0038    .129536E 01=003A    .986000E 01=003C    .100000E 00=003E    .466770E 01=0040
  .100000E-01=0042    .112350E 01=0044    .100000E-02=0046    .400000E 01=0048    .100000E-04=004A    .200000E 01=004C
  .300000E 01=004E    .434294E 00=0050    .100000E 02=0052

INTEGER CONSTANTS
     1=0054     20=0055      2=0056      3=0057      4=0058

CORE REQUIREMENTS FOR CORE
 COMMON       0  VARIABLES      42  PROGRAM     426

RELATIVE ENTRY POINT ADDRESS IS 0063 (HEX)

END OF COMPILATION

// DUP

*STORE      WS  UA  CORE
CART ID 0105   DB ADDR  5820   DB CNT   0022

// FOR
*ONE WORD INTEGERS
*LIST ALL
      SUBROUTINE SBM36
      COMMON DP,RHO,SIGMA,XMU,RE,VT
C
C     THIS SUBROUTINE CALCULATES THE TERMINAL VELOCITY
C     OF A SPHERICAL PARTICLE IN AIR AS A FUNCTION OF
C     PARTICLE DENSITY AND DIAMETER
C
      G = 981.0
      XNU = XMU/RHO
      CDRN = 24.0
      RN = 1.0
      FRHO =4.0*(SIGMA - RHO)*G*XNU/(3.0*RHO)
      VT=(FRHO*RN**2/CDRN)**(1.0/3.0)
```

```
      DO 6 ITER=1,100
      RE =VT*DP/XNU
      OLDV = VT
      VT=(FRHO*RE**2/CDRE(RE))**(1.0/3.0)
C
C     CHECK CONVERGENCE
C
      EPS = 1.E-03
      IF(ABS(VT-OLDV)- EPS)5,5,6
    5 CONTINUE
      GO TO 30
    6 CONTINUE
      WRITE(3,200)
   30 RETURN
C
C     FORMAT FOR OUTPUT STATEMENT
C
  200 FORMAT(16H0 NO CONVERGENCE)
      END
VARIABLE ALLOCATIONS
   DP(RC)=7FFE        RHO(RC)=7FFC      SIGMA(RC)=7FFA       XMU(RC)=7FF8        RE(RC)=7FF6         VT(RC)=7FF4
    G(R )=0000        XNU(R )=0002       CDRN(R )=0004        RN(R )=0006      FRHO(R )=0008       OLDV(R )=000A
  EPS(R )=000C       ITER(I )=0014

STATEMENT ALLOCATIONS
 200  =0026  5    =00AC  6    =00AE  30   =00BB

FEATURES SUPPORTED
 ONE WORD INTEGERS

CALLED SUBPROGRAMS
 CDRE     FABS     FAXB     FSUB     FMPY     FDIV     FLD      FSTO     FDVR     FAXI     SWRT     SCOMP

REAL CONSTANTS
  .981000E 03=0016    .240000E 02=0018    .100000E 01=001A    .400000E 01=001C    .300000E 01=001E    .100000E-02=0020

INTEGER CONSTANTS
    2=0022      1=0023    100=0024      3=0025

CORE REQUIREMENTS FOR SBM36
 COMMON      12  VARIABLES      22  PROGRAM     168

RELATIVE ENTRY POINT ADDRESS IS 0030 (HEX)

END OF COMPILATION
```

```
// DUP

*STORE      WS  UA  SBM36
CART ID 0105   DB ADDR  5B42   DB CNT   000E

// FOR
*ONE WORD INTEGERS
*IOCS(CARD)
*IOCS(1132 PRINTER)
*LIST ALL
      COMMON DP,RHO,SIGMA,XMU,RE,VT
C
C     INPUT DATA
C
C     DP IS PARTICLE DIAMETER CM
C     RHO IS AIR DENSITY GM PER CUBIC CM
C     SIGMA IS PARTICLE DENSITY GM PER CUBIC CM
C     XMU IS AIR DYNAMIC VISCISITY GM PER CM SEC
C
    1 READ(2,100)DP,RHO,SIGMA,XMU
      CALL SBM36
      WRITE(3,200)DP,RHO,SIGMA,XMU,RE
      WRITE(3,201)VT
      WRITE(3,202)
      WRITE(3,203)
C
C     CALCULATE CONSTANTS
C
      REF = DP*RHO/XMU
      A = 981.0*(1.0 -RHO/SIGMA)
      B = 0.75*XMU/(SIGMA*DP**2)
      DELV = VT/100.0
      X = 0.0
      V = 0.0
      T = 0.0
      VR = 0.0
      ITER = 98
      WRITE(3,204) T,V,X,VR
C
C     CALCULATE TIME AND DISTANCE FOR EACH VELOCITY INCREMENT
C
      DO 26 I = 1,ITER
      V = FLOAT(I)* DELV
      RE = V*REF
      DELT =     DELV/(A - B*CDRE(RE)*V)
      T = T + DELT
```

```
      DELX = V*DELT
      X = X + DELX
      VR = V/VT
C
C     CALCULATE TERMINAL VELOCITY OF LIQUID DROP BY BEST'S EQUATION
C
      VTB = 943.0*(1.-EXP(-(DP/0.177)**1.147))
C
C     OUTPUT RESULTS
C
      IS = I/4*4
      IF(IS-I)21,23,21
   21 IF(I-1)22,23,22
   22 IF(I-ITER)24,23,24
   23 CONTINUE
      WRITE(3,204) T,V,X,VR
   24 CONTINUE
   26 CONTINUE
      WRITE(3,205)VTB
      READ(2,111)NSTOP
      IF(NSTOP)1,30,50
   30 CALL EXIT
C
C     FORMATS FOR INPUT AND OUTPUT STATEMENTS
C
  100 FORMAT(4F10.7)
  111 FORMAT(I5)
  200 FORMAT(10H1DP       =  ,F10.7/10H RHO     =  ,F10.6/
     110H SIGMA =  ,F10.6/10H XMU     =  ,F10.7/10H RE      =  ,E10.4)
  201 FORMAT(27H0THE TERMINAL VELOCITY IS  ,F10.3, 8H CM/SEC )
  202 FORMAT(1H0, 50H    THE DISTANCE DROPPED IN AIR AS A FUNCTION OF
     1/           51H VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER
     2/             20H STARTING FROM REST /1H0)
  203 FORMAT(1H0,     5H TIME,17X,    9H VELOCITY,13X,9H DISTANCE,8X,
     115H VELOCITY RATIO
     2/              1X,4H SEC    ,19X,7H CM/SEC ,16X,3H CM ,17X,5H V/VT
     3/1H0)
  204 FORMAT(     F8.5, 13X,F10.3,11X,F10.3,13X,F6.3)
  205 FORMAT( 62H0THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUAT
     1ION IS ,F10.3,8H CM/SEC )
      END
VARIABLE ALLOCATIONS
   DP(RC)=7FFE        RHO(RC)=7FFC      SIGMA(RC)=7FFA       XMU(RC)=7FF8        RE(RC)=7FF6         VT(RC)=7FF4
  REF(R )=0000          A(R )=0002          B(R )=0004      DELV(R )=0006         X(R )=0008          V(R )=000A
    T(R )=000C         VR(R )=000E       DELT(R )=0010      DELX(R )=0012       VTB(R )=0014       ITER(I )=0018
    I(I )=0019         IS(I )=001A      NSTOP(I )=001B
```

```
STATEMENT ALLOCATIONS
 100  =0031  111  =0034  200  =0035  201  =005E  202  =0074  203  =00BC  204  =00F2  205  =00FA  1    =0138  21   =0202
 22   =0208  23   =020E  24   =021A  26   =021A  30   =0232

FEATURES SUPPORTED
 ONE WORD INTEGERS
 IOCS

CALLED SUBPROGRAMS
 SRM36    CORE     FEXP     FAXB     FADD     FMPY     FDIV     FLD      FSTO     FSBR     FDVR     FAXI     FLOAT    CARDZ    PRNTZ
 SRED     SWRT     SCOMP    SFIO     SIOF     SIOI     SNR

REAL CONSTANTS
  .981000E 03=001C    .100000E 01=001E    .750000E 00=0020    .100000E 03=0022    .000000E 00=0024    .943000E 03=0026
  .177000E 00=0028    .114700E 01=002A

INTEGER CONSTANTS
      2=002C      3=002D      98=002E      1=002F      4=0030

CORE REQUIREMENTS FOR
 COMMON      12  VARIABLES      28  PROGRAM     536

END OF COMPILATION

// XEQ
```

```
DP     =  0.1000000
RHO    =  0.001213
SIGMA  =  1.000000
XMU    =  0.0001789
RE     =  0.2636E 03
```

THE TERMINAL VELOCITY IS 388.914 CM/SEC

THE DISTANCE DROPPED IN AIR AS A FUNCTION OF VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/VT
0.00000	0.000	0.000	0.000
0.00397	3.889	0.015	0.009
0.01596	15.556	0.155	0.039
0.03213	31.113	0.564	0.079
0.04857	46.669	1.236	0.119
0.06537	62.226	2.183	0.159
0.08257	77.782	3.422	0.199
0.10025	93.339	4.970	0.239
0.11850	108.896	6.851	0.279
0.13740	124.452	9.094	0.319
0.15705	140.009	11.732	0.359
0.17758	155.565	14.806	0.399
0.19912	171.122	18.369	0.439
0.22186	186.679	22.481	0.479
0.24599	202.235	27.224	0.519
0.27180	217.792	32.696	0.559
0.29962	233.349	39.029	0.599
0.32991	248.905	46.395	0.639
0.36328	264.461	55.030	0.679
0.40059	280.018	65.265	0.719
0.44311	295.575	77.592	0.759
0.49282	311.131	92.779	0.799
0.55308	326.688	112.127	0.839
0.63027	342.244	138.121	0.879
0.73916	357.801	176.503	0.919
0.93009	373.358	246.843	0.959
1.13748	381.136	325.566	0.979

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS 382.079 CM/SEC

```
DP     =   0.1500000
RHO    =   0.001213
SIGMA  =   1.000000
XMU    =   0.0001789
RE     =   0.5511E 03
```

THE TERMINAL VELOCITY IS 541.892 CM/SEC

THE DISTANCE DROPPED IN AIR AS A FUNCTION OF VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/VT
0.00000	0.000	0.000	0.000
0.00553	5.418	0.030	0.010
0.02221	21.675	0.301	0.040
0.04467	43.351	1.092	0.080
0.06746	65.027	2.390	0.119
0.09067	86.702	4.214	0.160
0.11440	108.378	6.594	0.199
0.13873	130.054	9.562	0.239
0.16379	151.730	13.161	0.280
0.18967	173.405	17.441	0.320
0.21653	195.081	22.465	0.359
0.24452	216.757	28.306	0.399
0.27384	238.432	35.060	0.439
0.30470	260.108	42.840	0.479
0.33740	281.784	51.792	0.519
0.37229	303.460	62.101	0.560
0.40983	325.135	74.005	0.600
0.45061	346.811	87.822	0.640
0.49544	368.487	103.986	0.679
0.54547	390.162	123.110	0.719
0.60239	411.838	146.096	0.759
0.66877	433.514	174.359	0.799
0.74910	455.190	210.298	0.840
0.85180	476.865	258.489	0.879
0.99643	498.541	329.514	0.920
1.24951	520.217	459.429	0.959
1.52409	531.055	604.647	0.980

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS 530.606 CM/SEC

```
DP    =   0.2000000
RHO   =   0.001213
SIGMA =   1.000000
XMU   =   0.0001789
RE    =   0.9088E 03
```

THE TERMINAL VELOCITY IS 670.230 CM/SEC

THE DISTANCE DROPPED IN AIR AS A FUNCTION OF VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/VT
0.00000	0.000	0.000	0.000
0.00684	6.702	0.045	0.009
0.02745	26.809	0.460	0.039
0.05517	53.618	1.668	0.079
0.08326	80.427	3.646	0.119
0.11183	107.236	6.423	0.159
0.14098	134.046	10.039	0.199
0.17083	160.855	14.543	0.239
0.20152	187.664	19.995	0.279
0.23317	214.473	26.468	0.319
0.26597	241.283	34.053	0.359
0.30009	268.092	42.860	0.399
0.33576	294.901	53.026	0.439
0.37327	321.710	64.720	0.479
0.41294	348.520	78.153	0.519
0.45521	375.329	93.599	0.559
0.50062	402.138	111.408	0.599
0.54987	428.947	132.050	0.639
0.60394	455.756	156.161	0.679
0.66419	482.566	184.646	0.719
0.73263	509.375	218.834	0.759
0.81236	536.184	260.813	0.799
0.90868	562.993	314.117	0.839
1.03157	589.803	385.494	0.879
1.20463	616.612	490.546	0.919
1.50686	643.421	682.435	0.959
1.83441	656.826	896.697	0.979

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS 644.536 CM/SEC

DP = 0.2500000
RHO = 0.001213
SIGMA = 1.000000
XMU = 0.0001789
RE = 0.1323E 04

THE TERMINAL VELOCITY IS 780.60[illegible] CM/SEC

THE DISTANCE DROPPED I[illegible] AIR AS A FUNCTION OF VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/VT
0.00000	0.000	0.000	0.000
0.00797	7.806	0.062	0.009
0.03196	31.224	0.624	0.039
0.06420	62.448	2.260	0.079
0.09683	93.672	4.936	0.119
0.12998	124.896	8.690	0.159
0.16377	156.120	13.571	0.199
0.19834	187.344	19.644	0.239
0.23382	218.568	26.986	0.279
0.27037	249.792	35.693	0.319
0.30820	281.016	45.883	0.360
0.34751	312.240	57.700	0.399
0.38856	343.464	71.324	0.439
0.43167	374.688	86.977	0.479
0.47721	405.912	104.937	0.519
0.52568	437.136	125.562	0.559
0.57767	468.360	149.317	0.599
0.63402	499.584	176.816	0.639
0.69580	530.808	208.902	0.679
0.76456	562.032	246.763	0.720
0.84257	593.256	292.156	0.759
0.93336	624.480	347.828	0.799
1.04293	655.704	418.443	0.839
1.18267	686.928	512.897	0.879
1.37897	718.152	651.765	0.919
1.72164	749.376	905.151	0.959
2.09275	764.988	1187.883	0.980

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS 729.616 CM/SEC

```
DP     =  0.3000000
RHO    =   0.001213
SIGMA  =   1.000000
XMU    =  0.0001789
RE     =  0.1784E 04
```

THE TERMINAL VELOCITY IS 877.296 CM/SEC

THE DISTANCE DROPPED IN AIR AS A FUNCTION OF VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/VT
0.00000	0.000	0.000	0.000
0.00896	8.772	0.078	0.010
0.03591	35.091	0.788	0.040
0.07210	70.183	2.852	0.080
0.10871	105.275	6.226	0.120
0.14586	140.367	10.954	0.160
0.18370	175.459	17.097	0.199
0.22236	210.551	24.731	0.240
0.26201	245.642	33.953	0.280
0.30283	280.734	44.878	0.320
0.34502	315.826	57.651	0.359
0.38882	350.918	72.450	0.399
0.43452	386.010	89.494	0.439
0.48245	421.102	109.056	0.480
0.53305	456.194	131.482	0.519
0.58684	491.285	157.209	0.560
0.64450	526.377	186.811	0.600
0.70691	561.469	221.047	0.640
0.77529	596.561	260.956	0.679
0.85131	631.653	308.003	0.719
0.93749	666.745	364.356	0.759
1.03769	701.837	433.408	0.799
1.15849	736.928	520.913	0.840
1.31244	772.020	637.854	0.879
1.52849	807.112	809.625	0.920
1.90529	842.204	1122.762	0.960
2.31311	859.750	1471.950	0.979

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS 791.973 CM/SEC

```
DP     =   0.3500000
RHO    =   0.001213
SIGMA  =   1.000000
XMU    =   0.0001789
RE     =   0.2285E 04
```

THE TERMINAL VELOCITY IS   963.235 CM/SEC

THE DISTANCE DROPPED IN AIR AS A FUNCTION OF VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/VT
0.00000	0.000	0.000	0.000
0.00983	9.632	0.094	0.009
0.03941	38.529	0.949	0.039
0.07912	77.058	3.436	0.079
0.[illegible]925	115.588	7.497	0.119
0.[illegible]996	154.117	13.184	0.159
0.[illegible]138	192.647	20.567	0.199
0.24367	231.176	29.736	0.239
0.28700	269.705	40.801	0.279
0.33158	308.235	53.900	0.319
0.37761	346.764	69.203	0.360
0.42536	385.294	86.918	0.399
0.47514	423.823	107.303	0.439
0.52732	462.353	130.681	0.479
0.58235	500.882	157.458	0.519
0.64080	539.411	188.152	0.559
0.70340	577.941	223.441	0.599
0.77110	616.470	264.220	0.639
0.84522	655.000	311.718	0.680
0.92757	693.529	367.667	0.720
1.02083	732.059	434.630	0.759
1.12919	770.588	516.618	0.799
1.25973	809.118	620.434	0.840
1.42595	847.647	759.066	0.879
1.65904	886.176	962.545	0.919
2.06526	924.706	1333.199	0.959
2.50471	943.971	1746.329	0.980

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS   837.023 CM/SEC

DP = 0.4000000
RHO = 0.001213
SIGMA = 1.000000
XMU = 0.0001789
RE = 0.2821E 04

THE TERMINAL VELOCITY IS 1040.483 CM/SEC

THE DISTANCE DROPPED IN AIR AS A FUNCTION OF
VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER
STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/VT
0.00000	0.000	0.000	0.000
0.01062	10.404	0.110	0.009
0.04257	41.619	1.108	0.039
0.08543	83.238	4.007	0.079
0.12872	124.857	8.739	0.120
0.17261	166.477	15.363	0.159
0.21724	208.096	23.957	0.200
0.26278	249.715	34.621	0.240
0.30941	291.335	47.483	0.280
0.35734	332.954	62.698	0.319
0.40681	374.573	80.460	0.360
0.45809	416.193	101.006	0.400
0.51150	457.812	124.634	0.439
0.56744	499.431	151.711	0.480
0.62641	541.051	182.702	0.519
0.68899	582.670	218.202	0.560
0.75596	624.289	258.986	0.600
0.82836	665.909	306.084	0.639
0.90755	707.528	360.901	0.679
0.99547	749.147	425.429	0.720
1.09498	790.767	502.605	0.759
1.21051	832.386	597.032	0.800
1.34960	874.005	716.519	0.839
1.52658	915.625	875.971	0.879
1.77461	957.244	1109.848	0.919
2.20657	998.863	1535.598	0.960
2.67364	1019.673	2009.908	0.979

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS 869.194 CM/SEC

```
DP    =  0.4500000
RHO   =   0.001213
SIGMA =   1.000000
XMU   =  0.0001789
RE    =  0.3388E 04
```

THE TERMINAL VELOCITY IS 1110.554 CM/SEC

THE DISTANCE DROPPED IN AIR AS A FUNCTION OF VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/VT
0.00000	0.000	0.000	0.000
0.01134	11.105	0.125	0.009
0.04543	44.422	1.262	0.039
0.09115	88.844	4.563	0.079
0.13731	133.266	9.949	0.119
0.18408	177.688	17.482	0.159
0.23162	222.110	27.252	0.199
0.28010	266.533	39.368	0.239
0.32970	310.955	53.972	0.279
0.38066	355.377	71.238	0.319
0.43322	399.799	91.382	0.359
0.48767	444.221	114.669	0.399
0.54435	488.644	141.431	0.439
0.60369	533.066	172.080	0.479
0.66618	577.488	207.139	0.519
0.73246	621.910	247.273	0.559
0.80336	666.332	293.352	0.599
0.87994	710.755	346.530	0.639
0.96366	755.177	408.387	0.679
1.05656	799.599	481.156	0.719
1.16163	844.021	568.135	0.759
1.28355	888.443	674.492	0.799
1.43024	932.865	808.995	0.839
1.61678	977.288	988.375	0.879
1.87805	1021.710	1251.326	0.919
2.33279	1066.132	1729.709	0.959
2.82428	1088.343	2262.435	0.979

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS 891.944 CM/SEC

```
DP     =   0.5000001
RHO    =    0.001213
SIGMA  =    1.000000
XMU    =   0.0001789
RE     =  0.3982E 04
```

THE TERMINAL VELOCITY IS 1174.606 CM/SEC

THE DISTANCE DROPPED IN AIR AS A FUNCTION OF VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/VT
0.00000	0.000	0.000	0.000
0.01199	11.746	0.140	0.009
0.04804	46.984	1.411	0.039
0.09637	93.968	5.103	0.079
0.14516	140.952	11.122	0.119
0.19456	187.937	19.538	0.159
0.24475	234.921	30.447	0.199
0.29590	281.905	43.970	0.239
0.34822	328.889	60.260	0.279
0.40194	375.874	79.510	0.319
0.45731	422.858	101.955	0.360
0.51464	469.842	127.889	0.399
0.57429	516.826	157.675	0.439
0.63669	563.811	191.770	0.479
0.70237	610.795	230.747	0.519
0.77201	657.779	275.342	0.559
0.84645	704.763	326.514	0.600
0.92682	751.748	385.537	0.639
1.01463	798.732	454.154	0.679
1.11200	845.716	534.831	0.720
1.22208	892.700	631.211	0.759
1.34974	939.685	748.998	0.799
1.50325	986.669	897.876	0.839
1.69837	1033.653	1096.321	0.879
1.97150	1080.637	1387.066	0.919
2.44664	1127.622	1915.735	0.959
2.96001	1151.114	2504.264	0.979

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS 907.895 CM/SEC
// PAUS

APPENDIX B

COMPUTER PROGRAM FOR DISTANCE TRAVELLED FROM REST TO UPWARD TERMINAL VELOCITY FOR SPHERES IN A VERTICAL AIR STREAM

```
PAGE   1

// JOB T

LOG DRIVE   CART SPEC   CART AVAIL  PHY DRIVE
  0000        0302        0302        0000

V2 M10   ACTUAL 16K  CONFIG 16K

// FOR
*ONE WORD INTEGERS
*LIST ALL
C
      FUNCTION CDRE(RE)
C
C     THIS FUNCTION COMPUTES THE PRODUCT OF DRAG COEFFICIENT
C     AND REYNOLDS NUMBER FOR A SPHERE AS A FUNCTION OF
C     REYNOLDS NUMBER LESS THAN 10000
C
C     CONSTANT COEFFICIENTS
C
      A1=1./24.
      A2=-2.3363*1.E-04
      A3=2.0154*1.E-06
      A4=-6.9105*1.E-09
      B0=-1.29536
      B1=9.86*1.E-01
      B2=-4.6677*1.E-02
      B3=1.1235*1.E-03
C
C     CHOOSE THE APPROPRIATE POLYNOMIAL
C
      IF(RE-4.0)2,7,7
C
C     INITIAL ESTIMATE
C
    2 IF(RE-0.00001)3,4,4
    3 CDRE = 24.0
      GO TO 50
    4 X=24.*RE
C
C     BEGIN NEWTON METHOD ITERATION
C
      CONTINUE
      DO 6 ITER=1,20
      FX=A1*X+A2*X**2+A3*X**3+A4*X**4-RE
      FPX=A1+2.*A2*X+3.*A3*X**2+4.*A4*X**3
      DELX=FX/FPX
```

```
      X=X-DELX
C
C     CHECK FOR CONVERGENCE
C
      EPS=1.E-06
      IF(ABS(DFLX/X)-EPS)5,5,6
    5 CDRF=X/RF
      GO TO 50
    6 CONTINUE
      GO TO 29
C
C     INITIAL ESTIMATE
C
    7 CD = 1.0
      ELOG = 0.434294481903252
      X=ALOG(CD*RE**2)*ELOG
C
C     BEGIN NEWTON METHOD ITERATION
C
      DO 24 ITER=1,20
      FX=B0+B1*X+B2*X**2+B3*X**3 - ALOG(RE)*ELOG
      FPX=B1+2.*B2*X+3.*B3*X**2
      DFLX=FX/FPX
      X=X-DELX
C
C     CHECK FOR CONVERGENCE
C
      EPS=1.E-06
      IF(ABS(DFLX/X)-EPS)22,22,24
   22 CDRF=10.**X/RE
      GO TO 50
   24 CONTINUE
   29 WRITE(3,202)
   50 RETURN
C
C     FORMATS FOR OUTPUT STATEMENTS
C
  202 FORMAT(16H0 NO CONVERGENCE)
C
      END
VARIABLE ALLOCATIONS
  CDRE(R )=0000      A1(R )=0002      A2(R )=0004      A3(R )=0006      A4(R )=0008      B0(R )=000A
    B1(R )=000C      B2(R )=000E      B3(R )=0010       X(R )=0012      FX(R )=0014     FPX(R )=0016
  DELX(R )=0018     EPS(R )=001A      CD(R )=001C    ELOG(R )=001E    ITER(I )=0028

STATEMENT ALLOCATIONS
 202  =0059  2   =00AB  3   =00AF  4   =00B5  5   =012D  6   =0135  7   =0140  22  =01B8  24  =01C3  29  =01CC
```

```
PAGE   3

 50    =0100

FEATURES SUPPORTED
 ONE WORD INTEGERS

CALLED SUBPROGRAMS
 FABS     FALOG    FAXB      FADD      FSUB      FMPY      FDIV      FLD       FSTO      FSBR      FAXI      SQRT      SCOMP     SWR       SUBIN

REAL CONSTANTS
  .100000E 01=002A    .240000E 02=002C    .233630E 01=002E    .100000E-03=0030    .201540E 01=0032    .100000E-05=0034
  .691050E 01=0036    .100000E-08=0038    .129536E 01=003A    .986000E 01=003C    .100000E 00=003E    .466770E 01=0040
  .100000E-01=0042    .112350E 01=0044    .100000E-02=0046    .400000E 01=0048    .100000E-04=004A    .200000E 01=004C
  .300000E 01=004E    .434294E 00=0050    .100000E 02=0052

INTEGER CONSTANTS
     1=0054      20=0055       2=0056       3=0057       4=0058

CORE REQUIREMENTS FOR CORE
 COMMON       0  VARIABLES      42  PROGRAM     426

RELATIVE ENTRY POINT ADDRESS IS 0063 (HEX)

END OF COMPILATION

// DUP

*STORE       WS   UA   CORE
CART ID 0302    DB ADDR   3E40    DB CNT    0022

// FOR
*ONE WORD INTEGERS
*LIST ALL
      SUBROUTINE SRM36
      COMMON DP,RHO,SIGMA,XMU,RE,VT
C
C     THIS SUBROUTINE CALCULATES THE TERMINAL VELOCITY
C     OF A SPHERICAL PARTICLE IN AIR AS A FUNCTION OF
C     PARTICLE DENSITY AND DIAMETER
C
      G = 981.0
      XNU = XMU/RHO
      CORN = 24.0
      RN = 1.0
      FRHO =4.0*(SIGMA - RHO)*G*XNU/(3.0*RHO)
      VT=(FRHO*RN**2/CORN)**(1.0/3.0)
```

```
      DO 6 ITER=1,100
      RE =VT*DP/XNU
      OLDV = VT
      VT=(FRHO*RE**2/CORE(RE))**(1.0/3.0)
C
C     CHECK CONVERGENCE
C
      EPS = 1.E-03
      IF(ABS(VT-OLDV)- EPS)5,5,6
    5 CONTINUE
      GO TO 30
    6 CONTINUE
      WRITE(3,200)
   30 RETURN
C
C     FORMAT FOR OUTPUT STATEMENT
C
  200 FORMAT(16HC NO CONVERGENCE)
      END
VARIABLE ALLOCATIONS
    DP(RC)=7FFE        RHO(RC)=7FFC      SIGMA(RC)=7FFA      XNU(RC)=7FF8       RE(RC)=7FF6        VT(RC)=7FF4
     G(R )=0000        XNU(R )=0002       CORN(R )=0004       RN(R )=0006      FRHO(R )=0008      OLDV(R )=000A
   EPS(R )=000C       ITER(I )=0014

STATEMENT ALLOCATIONS
 200  =0026  5   =00AC  6   =00AE  30   =00B8

FEATURES SUPPORTED
 ONE WORD INTEGERS

CALLED SUBPROGRAMS
 CORE   FABS   FAXB   FSUB   FMPY   FDIV   FLD   FSTO   FDVR   FAXI   SWRT   SCOMP

REAL CONSTANTS
  .981000E 03=0016   .240000E 02=0018   .100000E 01=001A   .400000E 01=001C   .300000E 01=001E   .100000E-02=0020

INTEGER CONSTANTS
     2=0022      1=0023    100=0024      3=0025

CORE REQUIREMENTS FOR SRM36
 COMMON      12  VARIABLES      22  PROGRAM     168

RELATIVE ENTRY POINT ADDRESS IS 0030 (HEX)

END OF COMPILATION
```

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// DUP

*STORE      WS  UA  SBM36
CART ID 0302   DB ADDR  3E62   DB CNT   000F

// FOR
*ONE WORD INTEGERS
*IOCS(CARD)
*IOCS(1132 PRINTER)
*LIST ALL
      COMMON DP,RHO,SIGMA,XMU,RE,VT
C
C     INPUT DATA
C
C     DP IS PARTICLE DIAMETER CM
C     RHO IS AIR DENSITY GM PER CUBIC CM
C     SIGMA IS PARTICLE DENSITY GM PER CUBIC CM
C     XMU IS AIR DYNAMIC VISCISITY GM PER CM SEC
C
    1 READ(2,100)DP,RHO,SIGMA,XMU,U
      CALL SBM36
      WRITE(3,200)DP,RHO,SIGMA,XMU,RE,U
      WRITE(3,201)VT
      WRITE(3,202)
      WRITE(3,203)
C
C     CALCULATE CONSTANTS
C
      REF = DP*RHO/XMU
      A = 981.0*(1.0 -RHO/SIGMA)
      B = 0.75*XMU/(SIGMA*DP**2)
      VSTAR = U - VT
      DELV = VSTAR/100.0
      X = 0.0
      V = 0.0
      T = 0.0
      VR = 0.0
      ITER = 98
      WRITE(3,204) T,V,X,VR
C
C     CALCULATE TIME AND DISTANCE FOR EACH VELOCITY INCREMENT
C
      DO 26 I = 1,ITER
      V = FLOAT(I)* DELV
      VS = U - V
      RE = VS*REF
```

```
      DELT =  - DELV/(A - B*CDRE(RE)*VS)
      CDRX=CDRE(RE)
      DELX = V*DELT
      T = T + DELT
      X = X + DELX
      VR = V/VSTAR
C
C     CALCULATE PARTICLE VELOCITY AT TARGET POSITION
C
      IF(X-95.0)6,4,4
    4 IF(X-95.0-DELX)5,5,6
    5 DXTAR = X-95.0
      TTAR = T -DELT*(DXTAR/DELX)
      VTAR = V - DELV*(DXTAR/DELX)
      XTAR = 95.0
      VRTAR = VTAR/VSTAR
      WRITE(3,204)TTAR,VTAR,XTAR,VRTAR
    6 CONTINUE
C
C     CALCULATE TERMINAL VELOCITY OF LIQUID DROP BY BEST'S EQUATION
C
      IF(DP-0.0300)20,20,10
   10 VTB = 943.0*(1.-EXP(-(DP/0.177)**1.147))
C
C     OUTPUT RESULTS
C
   20 IS = I/4*4
      IF(IS-I)21,23,21
   21 IF(I-1)22,23,22
   22 IF(I-ITER)24,23,24
   23 CONTINUE
      WRITE(3,204) T,V,X,VR
   24 CONTINUE
   26 CONTINUE
      IF(DP-0.0300)28,28,27
   27 CONTINUE
      WRITE(3,205)VTB
   28 CONTINUE
      READ(2,111)NSTOP
      IF(NSTOP)1,30,30
   30 CALL EXIT
C
C     FORMATS FOR INPUT AND OUTPUT STATEMENTS
C
  100 FORMAT(4F10.7,F10.2)
  111 FORMAT(I5)
```

```
 200 FORMAT(10H1DP     =  ,F10.7/10H RHO    =  ,F10.6/
    110H SIGMA =  ,F10.6/10H XMU    =  ,F10.7/10H RE     =  ,E10.4/
    210H U      =  ,F10.2)
 201 FORMAT(49H0THE DOWNWARD TERMINAL VELOCITY IN STILL AIR IS  ,F10.3,
    1 8H CM/SEC )
 202 FORMAT(1H0,  50H    THE DISTANCE TRAVELLED IN AIR AS A FUNCTION OF
    1/            51H VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER
    2/              20H STARTING FROM REST /1H0)
 203 FORMAT(1H0,     5H TIME,17X,     9H VELOCITY,13X,9H DISTANCE,8X,
    115H VELOCITY RATIO
    2/              1X,4H SEC    ,19X,7H CM/SEC ,16X,3H CM ,15X,
    39H V/(U-VT))
 204 FORMAT(     F8.5, 13X,F10.3,11X,F10.3,13X,F6.3)
 205 FORMAT( 62H0THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUAT
    1ION IS ,F10.3,8H CM/SEC )
     END
VARIABLE ALLOCATIONS
      DP(RC)=7FFF        RHO(RC)=7FFC      SIGMA(RC)=7FFA        XMU(RC)=7FF8          RE(RC)=7FF6           VT(RC)=7FF4
       U(R )=0000        REF(R )=0002          A(R )=0004          B(R )=0006      VSTAR(R )=0008         DELV(R )=000A
       X(R )=000C          V(R )=000E          T(R )=0010         VR(R )=0012         VS(R )=0014         DELT(R )=0016
    CDRX(R )=0018       DELX(R )=001A      DXTAR(R )=001C       TTAR(R )=001E       VTAR(R )=0020         XTAR(R )=0022
    VRTAR(R )=0024       VTR(R )=0026       ITER(I )=002A          I(I )=002B         IS(I )=002C        NSTOP(I )=002D

STATEMENT ALLOCATIONS
 100  =0047  111  =004B  200  =004D  201  =007D  202  =009E  203  =00E6  204  =011B  205  =0123  1    =0161  4    =0229
 5    =0232  6    =0262  10   =0269  20   =027C  21   =028C  22   =0292  23   =0298  24   =02A4  26   =02A4  27   =02B4
 28   =02BA  30   =02C3

FEATURES SUPPORTED
 ONE WORD INTEGERS
 IOCS

CALLED SUBPROGRAMS
 SRV36    CORE    FEXP    FAXB    FADD    FSUB    FMPY    FDIV    FLD    FSTO    FSBR    FDVR    FAXI    FLOAT   CARDZ
 PRNTZ    SRED    SWRT    SCOMP   SFIO    SIOF    SIOI    SNR

REAL CONSTANTS
  .981000E 03=002E    .100000E 01=0030    .750000E 00=0032    .100000E 03=0034    .000000E 00=0036    .950000E 02=0038
  .300000E-01=003A    .943000E 03=003C    .177000E 00=003E    .114700E 01=0040

INTEGER CONSTANTS
    2=0042       3=0043      98=0044      1=0045      4=0046

CORE REQUIREMENTS FOR
 COMMON      12  VARIABLES      46  PROGRAM     662
```

```
PAGE   8
END OF COMPILATION
// XEQ
```

```
DP     =  0.0470000
RHO    =   0.001213
SIGMA  =   2.600000
XMU    =  0.0001789
RE     = 0.1141E 03
U      =     700.00
```

THE DOWNWARD TERMINAL VELOCITY IN STILL AIR IS 358.114 CM/SEC

THE DISTANCE TRAVELLED IN AIR AS A FUNCTION OF VELOCITY BY A SPHERICAL PARTICLE OF GIVEN DIAMETER STARTING FROM REST

TIME SEC	VELOCITY CM/SEC	DISTANCE CM	VELOCITY RATIO V/(U-VT)
0.00000	0.000	0.000	0.000
0.00192	3.418	0.006	0.010
0.00784	13.675	0.067	0.040
0.01608	27.350	0.251	0.080
0.02477	41.026	0.563	0.120
0.03394	54.701	1.018	0.160
0.04363	68.377	1.632	0.199
0.05392	82.052	2.424	0.240
0.06486	95.727	3.415	0.280
0.07653	109.403	4.633	0.320
0.08902	123.078	6.107	0.360
0.10244	136.754	7.875	0.399
0.11693	150.429	9.981	0.439
0.13264	164.104	12.481	0.480
0.14978	177.780	15.442	0.519
0.16861	191.455	18.951	0.560
0.18945	205.131	23.122	0.600
0.21273	218.806	28.101	0.640
0.23906	232.481	34.090	0.679
0.26927	246.157	41.376	0.720
0.30458	259.832	50.377	0.759
0.34693	273.508	61.751	0.799
0.39957	287.183	76.612	0.840
0.46179	299.635	95.000	0.876
0.46873	300.859	97.087	0.879
0.56879	314.534	128.091	0.919
0.74875	328.209	186.380	0.960
0.94778	335.047	252.794	0.979

THE TERMINAL VELOCITY OF A LIQUID DROP BY BEST'S EQUATION IS 185.096 CM/SEC
// PAUS

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Security Classification

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13. ABSTRACT

The distance travelled as a function of velocity for falling spherical drops starting from rest was calculated. This was done for 1 to 5 millimetre spheres to determine the travel distance required for designing experiments where velocities approaching terminal are required. The results showed that 80 percent of terminal velocity is reached after spheres of unit density and diameter of 5 millimetres have fallen from rest through a distance of 7.5 metres. To achieve 85 percent of terminal velocity, an increase of only 5 percent, 9.5 metres is required. Also calculated was the velocity of particles blown upward from rest in a vertical airstream. This was done to provide information for comparison of experimental to theoretical results on the effect of dust on aerodynamic drag.

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KEY WORDS

Aerosols - Travel

Drops (Liquid)

Dust Particles

Aerodynamic Drag

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